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AT MOSS LANDING, CALIFORNIA

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ABSTRACT

Longshore currents were measured in the surf zone in the vicinity of Moss Landing on both sides of the head of Monterey Submarine Canyon. The measurements were made utilizing drift bottles introduced at 50 to 100 feet offshore. For the period covered, January through March 1966, the majority of the longshore currents measured were directed toward the canyon from both sides. It was found that the height of the tide and the offshore bar configuration have a considerable effect on the longshore circulation, in addition to the wave and beach parameters which have been suggested by previous investigators. A review is made of laboratory and field observations of longshore currents to date and a comparison is made between the results of this investigation and previous studies in other geographical areas.

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TABLE I

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Term	Units
a_b	Breaker Angle	degrees
B	Breaker depth / Breaker height	
C	Wave speed	ft / sec
d	Density of water	slugs / ft ^{3}
g	Acceleration due to gravity	ft / sec ^{2}
h_b	Depth at breaking	ft
H_b	Breaker height	ft
k	Hydraulic roughness coefficient	
L_b	Breaker crest length	ft
m	Beach slope	
Q	Breaker cross-sectional area	ft ^{2}
Q_L	Mass volume flux	slugs ft ^{3} / sec
Q_W	Hypothetical flux per unit mass	ft ^{3} / sec
T	Breaker period	sec
V	Longshore current speed	ft / sec
w	Width of surf zone	ft

Abbreviations	Term
DIR	Direction
EBB	Ebb stage
FLD	Flood stage
HGT	Height of tide
LOC	Location
SLK - H	Slack water at high tide
SLK - L	Slack water at low tide
SPD	Speed

1. Introduction.

The purposes of this investigation were: to determine the longshore current regime inside the surf zone at Moss Landing during the winter season; to test the feasibility of longshore current prediction by various theories; and to determine if a relationship existed between the observed surface longshore circulation near the head of Monterey Submarine Canyon and bottom circulation in the head of the canyon.

Longshore currents have been recognized as the primary builder and destroyer of beaches for many years. In this role as a mover of sand and other beach materials, longshore currents are of interest to various groups. Business and property owners near the ocean are understandably interested in whether their beaches are being eroded, building up, or unchanging in profile. Governmental and private engineering organizations are concerned with longshore currents in the construction of piers, breakwaters, and jetties, since the location of these structures is critical in determining the extent and amount of erosion and other changes to beach profile which will occur. In addition to the littoral transport effects, a knowledge of longshore circulation is of importance to operators of public and private beaches regarding the location of frequently occurring rip currents, which are often dangerous for inexperienced swimmers.

Probably the one organization most interested in the knowledge and prediction of longshore currents is the U. S. Navy, which must plan and conduct amphibious operations. In World War II, during which the most extensive amphibious operations in recent times were conducted, considerable difficulty was experienced in landing amphibious craft in the presence of a longshore current. At times the magnitude of this current was sufficient to cause a landing vehicle to broach, even though it had successfully negotiated the breakers [8]. This broaching frequently

occurred in conjunction with troughs landward of bars, since on a flat beach or where there is a bar, a light current can broach a boat that gets its stern stuck while retracting. Another specific effect is that an LVT may drift off range considerably due to the longshore current. The knowledge of rip current locations is quite important since the judicious use or avoidance of the rip currents can enhance the conduct of a landing. Rips are very useful to small craft operators as, during low tide, they often furnish the only means of reaching the beach. Since breakers are usually smaller in a rip current, the higher powered craft may use this area for approach but slower craft may need to avoid the rip because they are slowed even more by this relatively strong current; however, both types of craft may use the rip current to provide rapid withdrawal from the beach [15].

Studies of nearshore circulation were initiated at Scripps Institution of Oceanography during World War II [10]. Since that time the study of longshore currents using field and laboratory observations has been intensified, and proposals for a prediction system have been submitted by many investigators. As is true in many phases of oceanography, the very important and highly variable character of longshore currents requires much more theoretical and field study before it can be considered a well understood and predictable phenomenon.

A list of symbols and abbreviations used in the equations, tables, and illustrations discussed in this thesis is presented in Table I. Certain terms common to oceanography, but several of which have slightly variable meanings, are defined below as they are used in this thesis:

Backwash is that part of the uprush that runs back down the beach face.

Beach slope is the slope of the beach face from the high water line seaward to a point where the water depth is one and one-half feet.

Breaker angle is the acute angle between the crest of the breaking wave and the shoreline.

Breaker height is the height of the crest of the breaking wave above the bottom of the preceding trough.

Breaker crest length is the length of the crest of the breaking wave.

Breaker period is the average period of the predominant swell just prior to breaking.

Broaching is the turning of a vessel broadside to approaching waves.

Longshore current velocity is the mean direction and speed of the surface current parallel to the shoreline inside the surf zone.

Shoreline is the line of contact between still water level and land.

Surf zone is the area between the point where the waves initially break and the shoreline.

Station is a frequently used reference point along the beach.

Uprush is the flow of a thin sheet of water up the beach face that follows the final breaking of each wave on the shore.

Wave speed is the speed of the crest of the breaking wave in a direction perpendicular to the crest.

This thesis is composed of three parts as follows: the first part contains a review of the published theoretical and field studies on longshore currents; the second part outlines the methods and techniques used in conducting the Moss Landing study and a comparison of these techniques with previous investigations; while the last part consists of the presentation of results obtained and conclusions of this study with recommendations for further investigations.

2. Review of Previous Studies

Approaches used by other investigators in arriving at theoretical equations to predict longshore current velocities are basically quite

similar. All were derived from consideration of one or more of the basic laws of physics: the conservation of energy; the conservation of momentum; and the continuity principle. In the following discussion, a brief summary of the different approaches by several investigators will be presented and the particular theories which are tested with the data from Moss Landing will be discussed in detail.

Putnam, Munk and Traylor [8] derived a theoretical equation for predicting longshore current velocities utilizing certain relationships derived from solitary wave theory and considering the energy of the breaking wave. They assumed: that equilibrium conditions prevailed such that the fraction of energy available to maintain the longshore motion equals the rate of dissipation of mechanical energy by friction; and that the area of measurement was far enough from any obstruction on the beach that a full strength current was reached. Using these assumptions, a theoretical formula was derived:

$$V = L\left[(m\, H_b^2 \sin 2\, a_b)/\, T\right]^{\frac{1}{3}}$$

where

$$L = \left[0.871\, g\, s\, /\, k\right]^{\frac{1}{3}},$$

s is the percentage of the total energy used to produce longshore currents, and k is a friction parameter. The fraction of the total energy of the breaker, s, which is responsible for setting up longshore currents is small since the greater part of the wave energy in the breaker is either turned into heat or used in piling water against the shore, thereby setting up rip currents. The factor k was assumed to be a function of bottom roughness. The variables H_b, T and a_b can be predicted from weather maps; s and k are assumed to remain constant over a given beach [8]. Both k and s are quite difficult to determine, and in practice are found to vary considerably. In experiments by these investigators, s varied between 0.15 and 0.33, and k varied from 0.0070 to 0.385. Therefore,

this approach was not used for testing with the Moss Landing data.

Another approach used by Putnam, Munk and Traylor [8] involved consideration of the net flux of momentum, or equivalent force, applied by the breakers upon the water mass in the surf zone. The assumptions made in the derivation of this theory were the same as those made in the energy approach except with regard to the friction parameter k, which was found to be a function of the velocity. In this approach, the fraction of energy used to produce the longshore current need not be determined. The derivation of this theoretical equation using the momentum approach is summarized below.

Consider a volume of water extending between shore and the breaking waves, from surface to bottom, and over a width of beach, dx. Let Q represent the cross-secional area of a breaking wave crest moving with velocity C, L_b the length of the breaking wave, a_b the breaker angle, h_b the depth of water where the wave breaks, and d the density of water. The average momentum per unit surface area is

$$d\ Q\ C\ /\ L \qquad (1)$$

and the mean flux of momentum into the volume of water parallel to the shore is

$$C \sin a_b\ (d\ Q\ C\ /\ L) \cos a_b\ dx. \qquad (2)$$

At breaking of the wave, the water is slowed down by turbulent friction to the mean velocity of the longshore current V, and eventually flows out from the surf zone, giving a momentum flux outward of

$$V(d\ Q\ C\ /\ L) \cos a_b\ dx. \qquad (3)$$

The difference between (2) and (3) is

$$(C \sin a_b - V)(d\ Q\ C\ /\ L) \cos a_b\ dx \qquad (4)$$

which is the net flux of momentum. Assuming that the longshore current is maintained at an essentially constant rate, this force, (4), is balanced by frictional force along the bottom,

$$k\ d\ V^2\ w\ dx, \tag{5}$$

where k is the friction parameter and w is the distance along the bottom from shore to breaker line. Using equations (4) and (5), assuming

$$m = h_b / w, \tag{6}$$

and from solitary wave theory using

$$C = \left[g(h_b + H_b)\right]^{\frac{1}{2}} \tag{7}$$

and

$$h_b = 1.28\ H_b \tag{8}$$

the following equation is obtained:

$$V^2 = n(C \sin a_b - V), \tag{9}$$

where

$$n = (m\ Q \cos a_b) / (k\ T). \tag{9a}$$

Solving for V gives

$$V = (n / 2) \left[(1 + 4 \frac{C}{n} \sin a_b)^{\frac{1}{2}} - 1\right], \tag{10}$$

where

$$C = (2.28\ g\ H_b)^{\frac{1}{2}} \tag{11}$$

from (7) and (8). Also from solitary wave theory,

$$Q = 4\ h_b{}^2(H_b / 3\ h_b)^{\frac{1}{2}}. \tag{11a}$$

Substituting (11a) and (8) into (9a) gives

$$n = 2.61\ (m\ H_b \cos a_b) / (k\ T) \tag{12}$$

where according to (9),

$$k = (2.61\ m\ H_b \cos a_b)(C \sin a_b - V) / (T\ V^2).$$

Thus equation (10) gives the velocity of the longshore current as a function of the same variables that appeared in the energy approach, with the advantageous exception that no assumption has to be made regarding selection of the energy fraction.

Equation (10) was tested against a series of field observations by Inman and Quinn [9]. Using an empirically determined value for k of $0.024\ V^{-1.51}$, agreement between calculated and observed velocities was found to be within plus or minus 50 percent. Using this value for k, equation (10) becomes

$$V = \left[\left(\frac{1}{4\, X^2} + y \right)^{\frac{1}{2}} - \frac{1}{2\, X} \right]^2 \qquad (13)$$

where $x = (108.3\ H_b\ m \cos a_b) / T$

and $y = C \sin a_b$.

It would appear that this equation is the more valid of the two derived by Putnam, Munk and Traylor for three reasons: there is no dependence on the fractional energy parameter or the type of beach material; favorable agreement of the field observations with the velocities predicted by the theory; and relatively extensive field testing of this theory which has been conducted. Equation (13) was used in the calculations presented in Table V.

Brebner and Kamphius [2] assumed a plane beach of constant slope attacked by waves of constant deep water wave height and period. They derived a set of equations to predict the longshore current speed envelope to be expected for a given set of deep water wave characteristics. This approach assumed conservation of energy of the deep water waves and also that eight percent of the energy of a wave was used to maintain the longshore current. An angle of 55 degrees between the deep water wave crest and the shoreline was determined to yield the maximum velocities. This approach was not considered for comparison with the Moss Landing study since the deep water wave characteristics were not observed. It was considered by the authors that the restrictive assumptions of this theory concerning constant slope and constant wave characteristics may render it invalid in normal wave conditions and beach configurations in the surf zone.

A considerably different approach to predicting longshore currents was presented by Chiu and Bruun [3]. This approach involved consideration of the continuity principle and was the only study found which included the variation between single bar and multibar beaches.

The basic assumptions of this approach were: solitary wave theory was valid in the surf zone; statistical wave-height distribution for deep water waves with a single narrow band of frequencies was applicable near the shore; the water depth over the crest of the bar was equal to 0.8 H_b; and longshore current was either evenly distributed or a mean was taken. Chiu and Bruun made a comparison between calculations using equation (10) and their method. The results of this comparison showed that, in general, the momentum approach of Putnam, Munk and Traylor [8] yielded much higher longshore current velocities than the continuity approach of Chiu and Brunn [3]. They also showed that velocity decreases with increasing wave height in the continuity approach and increases with increasing wave height in the momentum approach. In the Moss Landing study, higher wave heights usually yielded higher longshore current velocities; therefore, the continuity approach was not considered appropriate for testing with the data from Moss Landing.

Galvin and Eagleson [5] made measurements of the characteristics of breaking waves and the resulting longshore currents for 34 combinations of wave height, period and breaker angle along a 20 foot test section of a smooth, concrete beach with a constant slope of 0.104. These observations led to an analysis of energy dissipation in the surf zone, an analytical description of the non-uniform flow of longshore currents, and an empirical correlation between the velocity of longshore currents, the wave conditions and beach geometry. This empirical correlation led to an equation for predicting the mean longshore current:

$$V = g\ m\ T \sin 2\ a_b. \qquad (14)$$

The derivation of this equation was achieved from their observations and from a thorough review of previous studies. Galvin and Eagleson found a correlation was possible between two groups of measured variables

for some of the available field and laboratory data. In one form, this correlation is between the mass volume flux of the longshore current, Q_L, and a hypothetical flux per unit mass, Q_W, where

$$Q_L = \frac{1}{2} m w^2 V, \tag{15}$$

and

$$Q_W = (\tfrac{1}{2} H_b L_b \cos a_b) C \sin a_b. \tag{16}$$

Using

$$B = h_b / H_b$$

and equation (6),

$$Q_L = \frac{1}{2} B^2 H_b{}^2 V / m. \tag{17}$$

Using equation (7), equation (16) becomes

$$Q_W = \frac{1}{4} g T H_b{}^2 (1 + B) \sin 2 a_b. \tag{18}$$

Combining equations (17) and (18) gives

$$Q_L / Q_W = \frac{2 B^2 V}{(1 + B)(g m T \sin 2 a_b)}, \tag{19}$$

or

$$V = K_1 g m T \sin 2 a_b. \tag{20}$$

Selected data from the investigations of Putnam, Munk and Traylor [8], Inman and Quinn [9], and this investigation were plotted and the slope of the best fit line to the resultant scatter diagram gave a value of one for K_1. Substitution of $K_1 = 1$ into (20) yields (14), which is one form of the conservation of mass in the surf zone [4].

In addition to the prediction of longshore current velocities, Galvin and Eagleson arrived at several other conclusions of interest as a result of their study: longshore currents flowed parallel to the shore and reached their highest velocities between the point of wave breaking and the shoreline; the energy required for maintenance of a uniform longshore current was less than 10 percent of the total energy of the breaking wave; most of the water injected into the surf zone when a wave breaks had been drawn from the surf zone and hence already had a longshore velocity component when it became part of the breaker; and that longshore currents were unsteady and non-uniform on natural beaches. The derivation of equation (14) was just as complex and involved as many considerations as

did equation (13), but due to its simplified form and dependence on fewer variables, calculations using equation (14) were much easier. Therefore, this equation was chosen for use with the Moss Landing data to determine if such a simplified prediction equation could result in current predictions comparable to those using equation (13).

Considerably more work has been accomplished on the subject of longshore currents than was included in the above review. However, the majority of these investigations have started with the original theory of Munk and Traylor and attempted to refine their basic approach. The majority of all studies on longshore currents has been conducted in the laboratory using wave tanks; therefore, the applicability of the results of these studies is to straight beaches with parallel bottom contours. The extension of these theories to the usual beach which is not straight and has irregular bottom topography probably accounts, at least in part, for weaknesses of the theories when related to field observations. Sufficient testing of the theories with field observations has not been done to determine the most valid or most nearly correct approach.

The one conclusion to be drawn from a review of the work in this field to date was that the wave-beach interactions in the surf zone that produce and maintain longshore currents do not obey any set rules or patterns exactly; however, the theoretical attempts to predict longshore currents are becoming more accurate with availability of more comprehensive field data. The primary difference in the prediction formulas now is the relative importance assigned to the parameters thought to be responsible for the production and maintenance of longshore currents.

3. Procedure.

Moss Landing is located approximately at the midpoint of the symmetrical shoreline of Monterey Bay (Figure 1). In addition to its

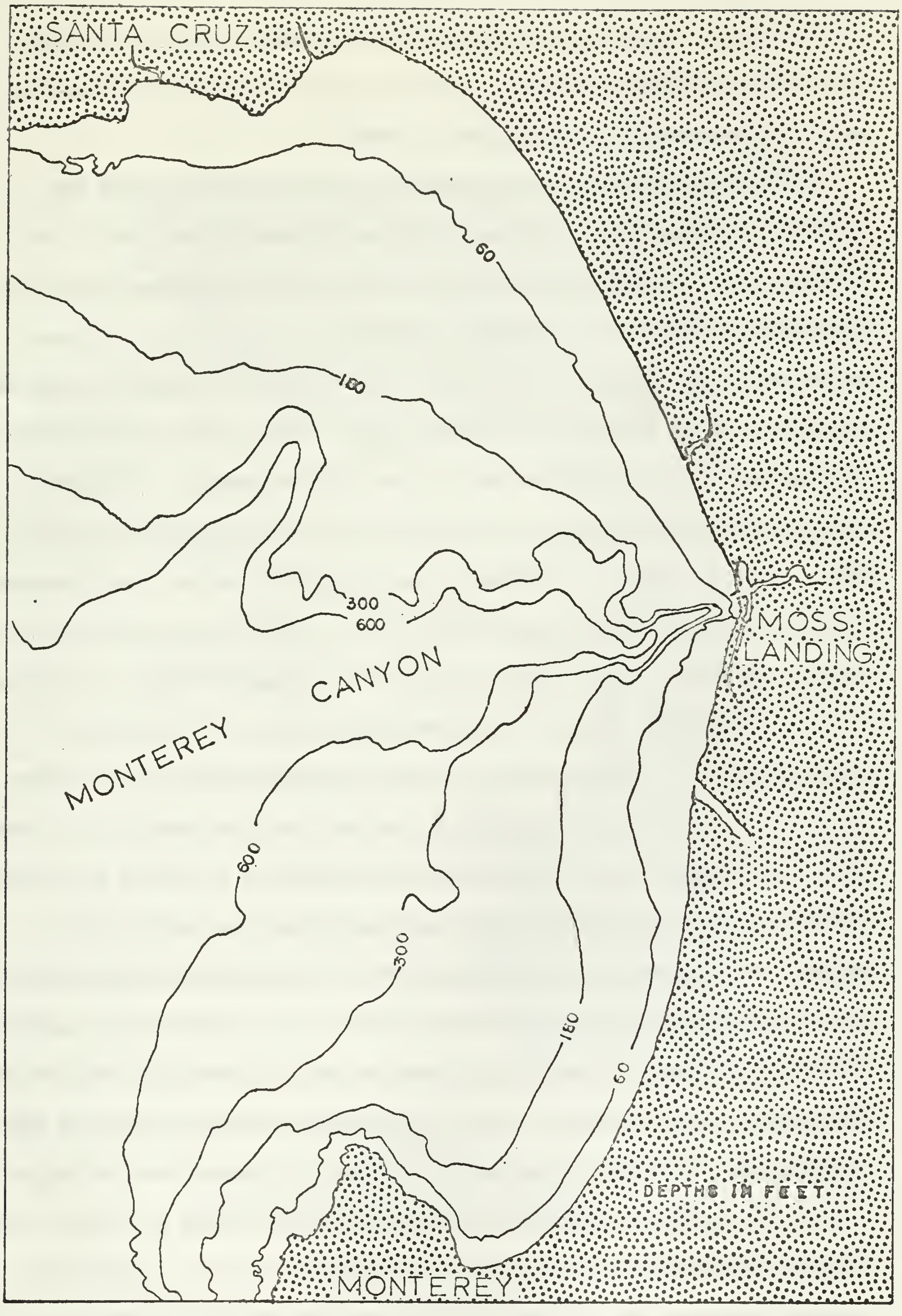

Figure 1.

Monterey Bay

oceanographic significance, Moss Landing is also an important fishing fleet port and industrial area, with two major industries now located here and consideration being given a third.

The average wave approach regime on the West Coast is from the northwest in winter and from the southwest in summer, but due to the location of Moss Landing in the easternmost part of Monterey Bay, it is shielded to the south by Monterey Peninsula and to the north by the Santa Cruz coast during both seasons so that the year-around average wave approach is from a westerly direction [16]. This fact is significant in determining the longshore current system at Moss Landing. The head of the Monterey Submarine Canyon is located just off the end of the pier and wave refraction due to the canyon also contributes to the establishment of the westerly wave approach regime [16]. The northwest-oriented shoreline to the north of the canyon head makes an angle of about 22 degrees with the southwest-oriented shoreline to the south. A line drawn perpendicularly to the shoreline north of the canyon bears 262 degrees true and a line drawn perpendicularly to the shoreline south of the canyon bears 284 degrees true. To an observer standing on the shore and looking seaward, deep water waves approaching from directions north of 262 degrees, will approach the shoreline north of the canyon from his right and waves approaching from directions south of 284 degrees will approach the shoreline south of the canyon from his left (Figure 2). Thus, waves approaching from directions within this natural envelope of 262 to 284 degrees will approach the shoreline north of the canyon from his right and will approach the shoreline south of the canyon from his left. This feature, coupled with the average westerly wave approach, which falls between northwest and southwest, indicates that longshore currents generated will be toward the head of the canyon. Even though bottom

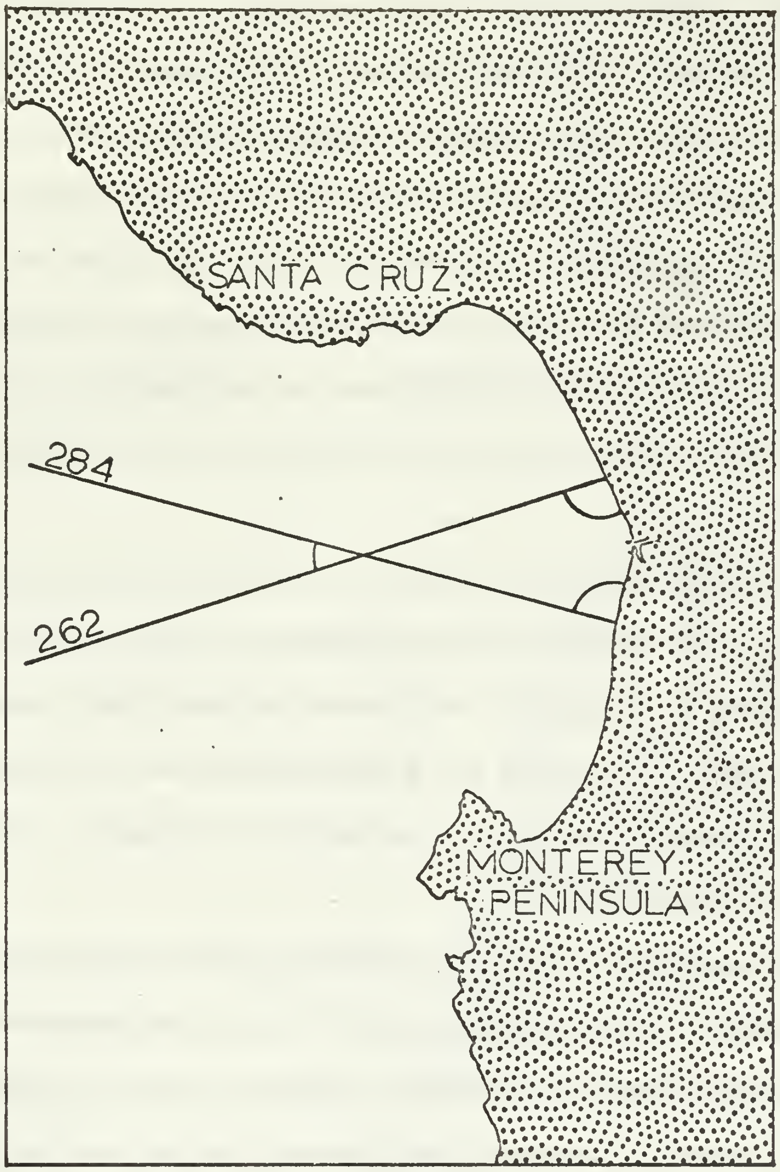

Figure 2.

Natural Envelope of Wave Approach

refraction tends to bend waves away from the canyon axis, these current directions still hold for waves within the envelope. Except for the head of the canyon, bottom contours in this area are nearly straight and parallel to the sand beach as shown in Figure 3; therefore, application of theories based on wave tank studies to this area is reasonable.

The surf zone at Moss Landing during the period of this investigation was approximately 400 feet wide on the average with as few as two and as many as eight lines of breakers. This surf zone was a modified single bar system; modified in that the bar was not continuous. The offshore bar topography was significant in determining the average rip current pattern observed here; rips were found only between bars or adjacent to a bar.

Longshore currents were measured in the surf zone one-half mile either side of the head of Monterey Submarine Canyon during the period from 13 January to 11 March, 1966, under variable tidal, weather, and wave conditions. A total of ten investigations were conducted at the rate of about one investigation per week, with several current observations during each investigation.

Current speeds were measured utilizing drift bottles introduced 50 to 100 feet seaward of the shoreline, that is, in the shoreward quarter of the surf zone. Five ounce plastic cylindrical drift bottles, 4 inches high and 2 inches in diameter, and one-half gallon plastic rectangular detergent bottles, 10 inches long and 6 inches wide, were used. The bottles were painted international orange for visual tracking and were filled with fresh water so one-fourth or less of the surface area was exposed. After several observations during which the drift of both sizes of bottles was identical, the larger bottles were used exclusively since they could be tracked more easily and much farther out into the surf zone

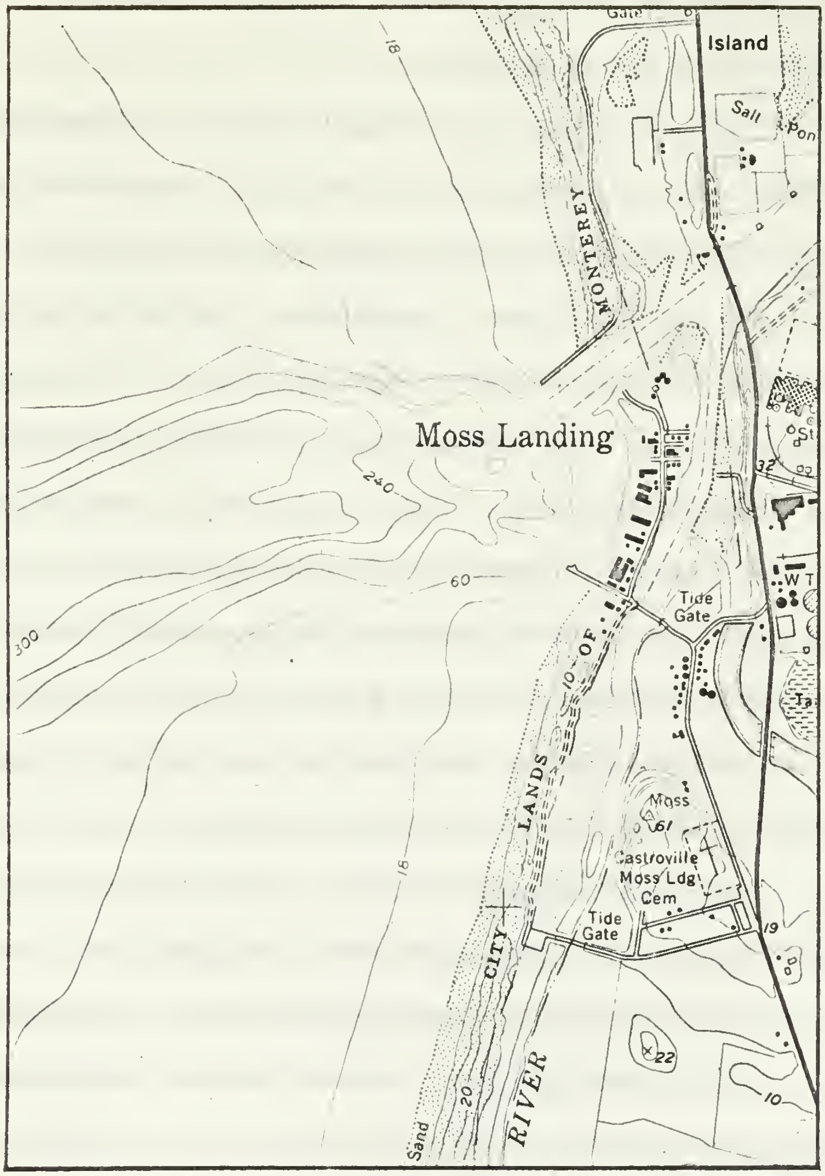

Figure 3.

Bathymetry at Moss Landing

and since it was desired to measure the mean current in the top one-half foot of the surface. However, since both bottles did exhibit identical drift, there appeared to be no vertical gradient of current within the first one-half foot of the surface.

Drift bottles were chosen as the best device for these current measurements because of the location in the surf zone where the water depth is quite variable, causing dragging along the bottom if a device projects too far into the water. Furthermore, the measuring device is subjected to the excessive force of breaking waves. A variety of other measuring devices have been used by others in previous investigations, such as the Ekman current meter, which could not be used in this environment for several reasons: no suitable platform from which to suspend the meter has been devised; the numerous small variabilities in current direction and speed would be measured and it would be very difficult if not impossible to sort out the mean longshore component; and the breaking waves and suspended sediment would cause damage to the instrument. Drogue measurements are also prohibited due to the variable water depth which would cause intermittent dragging of the device; these dragging times could not be determined accurately. Floating kelp has also been used in other investigations, but this was not considered for use in the Moss Landing study due to the difficulty in tracking it in the presence of foam. Currents were measured using Rhodamine B dye on several occasions. Due to the turbulence in the surf zone, the dye diffused so rapidly that it was impossible to determine the center of concentration after two or three minutes. On checking dye measured currents with drift bottle measured currents, it was found that the dye velocities were larger by a factor of two or more. This anomalous velocity was probably due to the rapid advance of water from the uprush and backwash of the

wave, and to diffusion. Putnam, Munk and Traylor [8] also found that the rapid diffusion of dye rendered it unusable for measuring longshore currents.

Tracking periods ranged from three minutes to one hour and 45 minutes. Due to the large variability in direction and speed of the longshore currents, tracking times of at least five minutes were considered desirable. Putnam, Munk and Traylor [8] found that five minutes was required for a steady state current to be established from a group of breaking waves and that longshore currents exhibit three to five minute variations due to the variation of wave height over a similar time interval. It was not unusual to observe a bottle drifting in one direction for two or three minutes, then reverse course for the next few minutes, then to repeat this cycle. In this case the mean longshore current was zero but a short tracking time could have yielded quite different results.

Positions were accurately determined by using a surveyor's transit for distance measurements from U. S. Army Corps of Engineers bench marks which are located strategically along this beach at stations C, F and I in Figure 4. The transit was used in conjunction with a graduated pole to measure beach slope. The angle of inclination was measured from the high water mark on the beach out to a point where the water depth was one and one-half feet. The tangent of this angle is the beach slope. It would be desirable to measure this parameter out to the point where the wave initially breaks but no safe method has been devised to accomplish this. The method used here, though not ideal, was considered by the authors to be more meaningful for calculation of longshore currents immediately adjacent to the beach than the other two methods which have been used in some previous studies: using bottom contours out to the point of breaking and assuming a constant beach slope from day to day and

year to year; or assuming the depth of the water at the breaking point of the wave is equal to 1.28 times the height of the wave. Since the beach slope was observed to vary considerably from day to day, the constant slope assumption would probably produce errors in current calculations. The measured slope which extended to the line of breakers nearest shore was chosen in preference to the solitary wave assumption above since the horizontal distance to the breaker line farthest offshore was not measured; and if a contour chart is used for this distance, one is back to the assumption that features remain constant for the time interval between charts. The value used for beach slope was critical in calculations using the theoretical equations and the values measured were quite variable as may be seen in Table III.

Breaker heights were determined utilizing a modification of the method suggested by Bascom [1]. In this procedure, the observer positions himself so that the breaker crest is on the horizon while he is standing half way between the limits of uprush and backwash. The height of the observer's eye level is then multiplied by four-thirds to account for the depression of the trough below still water level; this product is the breaker height. Due to the variability of the breaker heights, a series of observations must be taken to obtain the significant breaker height. The significant period of the waves was determined by taking the average period of several ten wave groups, using only the predominant swell in the observation.

The most difficult parameter to determine, and yet the most critical for calculations using any of the theoretical formulas, was the breaker angle. On all but two of the investigations, the breakers appeared to be nearly normal to the shoreline. Since the theory does not predict a longshore current for a zero breaker angle, estimates of these small

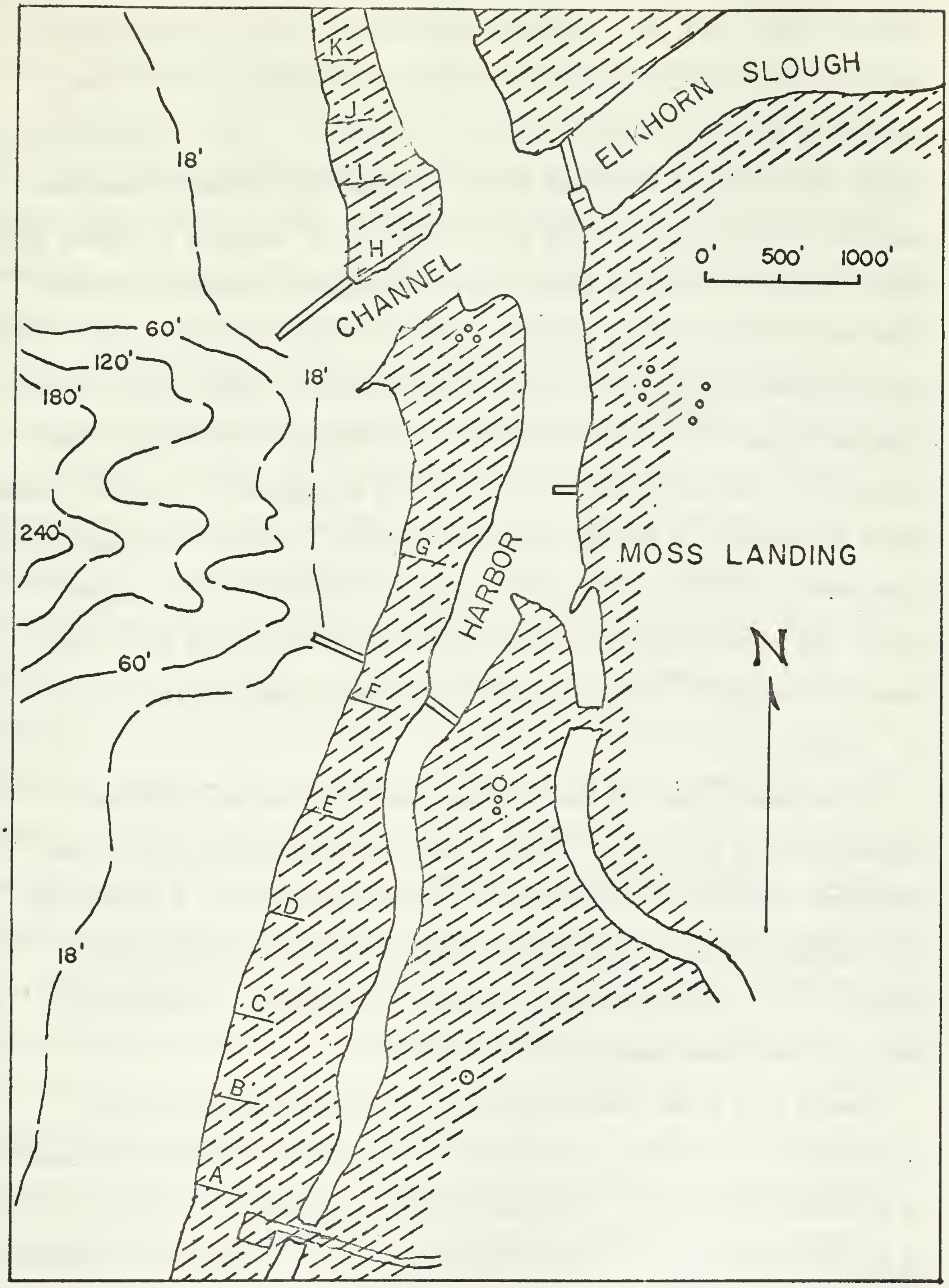

Figure 4.

Location of Stations on Moss Landing Beach

breaker angles were made. These estimates were made by standing on the shoreline and sighting perpendicularly to the breaker crest and then estimating the angle between the line of sight and a line perpendicular to the shoreline. A different method of determining breaker angle was devised by Forrest [4]. This method consists of mounting a transit high above the water level (at least one to two degrees elevation above the wave crests) and sighting perpendicularly to the face of the crest. The angle between the wave crest and the shoreline can then be read directly from the compass rose of the transit. According to Forrest [4], the average error of measurement is five or six degrees when using this method. After examination of several aerial photographs, the visual estimate was considered accurate to within five degrees for small breaker angles. Use of the Forrest method was not possible at Moss Landing due to the absence of suitable elevations on which to mount the transit.

4. Results.

Measurements from the Moss Landing investigation are displayed chronologically in tables. Table II shows the measured values of the longshore currents as well as other observed parameters. A summary of rip currents is shown in Table III, and is displayed graphically in Figure 6. The average values of longshore currents are tabulated in Table IV, and shown graphically in Figure 7.

Figure 3 is a map showing the beach at Moss Landing where the investigations were made. On Figure 4, the beach is divided into segments by stations A through K, from south to north. Convenient beach landmarks or features were used to locate the stations. The length of the segments varies from 400 feet to 1000 feet.

In Table II, measurements are listed chronologically by date and approximate time. A single letter in the column headed LOC indicates

that the measurement was made near that station. If the measurement was made in the segment between two stations, or over several segments, two station letters, separated by a hyphen such as "I-K", are listed under LOC. The other observed parameters listed in Table II describe the wind, beach slope, tide, and surf conditions existing when the currents were measured. Wind direction indicates the direction from which the wind was blowing while the wind speed is given in knots. Beach slope is listed in the column headed "m". The tide height is listed to the nearest foot; direction of flow is indicated by ebb stage or flood stage. Slack water is followed by an H or L, to indicate high or low tide, in the stage column. The tides were not measured but were taken from 1966 tide tables [14], and corrected for Moss Landing. Surf conditions are described by columns giving the significant breaker height in feet, the breaker angle in degrees, and the average period in seconds. Breaker angles are given to the nearest five degrees, followed by R or L to indicate right or left of a line extending seaward perpendicular to the beach. Measured longshore currents are listed, giving the direction N or S for current movement in a northerly or southerly direction respectively along the beach, with the speed indicated in feet per second.

Table III lists the occurrences of rip currents chronologically. The location of the rip currents and the tidal and surf conditions accompanying them are in the same format as in Table II. Rip current speeds were measured only at stations F and H. In both Table II and Table III, blank spaces in the columns indicate that no measurement was made of that item, while a dash in the column indicates that item was not applicable. Figure 6 shows the frequency of occurrence of rip currents during the ten investigations. The position of the rip currents is shown by double arrows pointing in the direction of flow. A number

adjacent to the current indicates the number of times that the rip current was present during the ten investigations.

The values of the longshore currents in Table II were assigned a plus sign for northward currents and a minus sign for southward currents and were summed, then averaged for each segment between the stations. These averages are presented in Table IV. The location of the segment is given in the first column, the direction of the average current in the second column, and the average velocity in feet per second in the third column. Figure 7 graphically displays the average circulation pattern as taken from the table of average currents. The rip currents at stations F and H show how the average flow feeds toward the head of the canyon.

Figure 5 shows the estimated location of offshore bars (stipled areas). Areas exposed at extremely low tides are indicated by cross-hatching over the stiple. These bars appeared to have a definite effect on the longshore currents at lower tide levels.

The currents were weak and the circulation was poorly defined on 13 January and 21 January. The circulation was well defined on 28 January and a dependence on slope was shown in the segments between stations C and F. The strongest flow on 28 January occurred along segment D-E where the slope was steepest. On 10 February, the flow was strong in a southerly direction along both the beach north of the canyon head and the beach south of the canyon head since the breaker approach was from the right in both cases. On 11 February the southerly current in segment B-C, opposing the direction of breaker approach, was a feeder to a rip current. This anomaly occurred again near station H on 19 February and near station A on 11 March. The strongest longshore current measured at anytime occurred near station F on 19 February. The longshore currents were strong and northerly in general on this date due to the high surf, short average period, and an unusually

TABLE II

SUMMARY OF LONGSHORE CURRENTS, WIND, TIDE AND SURF CONDITIONS

DATE	LOC	TIME	WIND		m	TIDE		SURF			LONGSHORE CURRENTS	
			DIR	SPD (KNOTS)		HGT (FT)	STG	H_b (FT)	a_b (DEG)	T (SEC)	DIR	SPD (FT/SEC)
13 JAN	A	1400	W	6.0		2	FLD	2.5			-	0
21 JAN	F-G	1130	ESE	8.0		4	EBB	2.0		6.0	-	0
21 JAN	A	1330	W	5.0	.049	2	EBB	2.0		6.0	-	0
21 JAN	B-C	1345	W	5.0	.049	2	EBB	2.0	$<$ 5 R	6.0	S	.40
21 JAN	I-K	1545	NW	9.5	.047	1	EBB	2.0	$<$ 5 R	6.0	S	.43
21 JAN	H-I	1600	NW	9.5	.047	0	EBB	2.0		6.0	-	0
28 JAN	I-K	1230	SE	7.0	.115	3	FLD	5.0	$<$ 5 R	8.6	S	.70
28 JAN	F-G	1445	SW	7.0		3	SLK-H	5.0		8.6	-	0
28 JAN	C-D	1520	WSW	8.5	.094	3	SLK-H	5.0	$<$ 5 L	8.6	N	.62
28 JAN	E-F	1545	WSW	8.5	.094	3	EBB	5.0	$<$ 5 L	8.6	N	.62
28 JAN	D-E	1600	WSW	8.5	.130	3	EBB	5.0	$<$ 5 L	8.6	N	1.01
10 FEB	I-K	1350	NNW	15.0	.091	3	FLD	4.0	$<$ 5 R	7.0	S	.94
10 FEB	H-I	1415	NNW	15.0	.091	4	SLK-H	4.0	$<$ 5 R	7.0	S	.90
10 FEB	A-F	1600	NNW	15.0	.063	3	EBB	4.0	$<$ 5 R	7.0	S	1.20

TABLE II (continued)

SUMMARY OF LONGSHORE CURRENTS, WIND, TIDE AND SURF CONDITIONS

DATE	LOC	TIME	WIND		m	TIDE		SURF			LONGSHORE CURRENTS	
			DIR	SPD (KNOTS)		HGT (FT)	STG	H_b (FT)	a_b (DEG)	T (SEC)	DIR	SPD (FT/SEC)
11 FEB	B-C	1200	E	3.0	.063	2	FLD	4.0	< 5 L	8.3	S	.40
11 FEB	A-B	1215	E	3.0	.063	2	FLD	4.0	< 5 L	8.3	-	0
11 FEB	D-E	1230	E	3.0	.063	2	FLD	4.0	< 5 L	8.3	N	.60
11 FEB	H-K	1415	W	8.0	.092	3	FLD	4.0	< 5 R	8.3	S	.89
17 FEB	I-K	1410	NW	9.0	.073	0	EBB	2.5	< 5 R	4.7	S	.80
17 FEB	H-I	1430	NW	9.0	.073	0	EBB	2.5	< 5 R	4.7	-	0
17 FEB	C	1515	W	10.0	.052	0	SLK-L	2.5	< 5 L	4.7	N	.41
19 FEB	F	0900	SSE	5.0		5	SLK-H	7.0	15 L	6.0	N	2.80
19 FEB	G	0900	SSE	5.0		5	SLK-H	7.0	15 L	6.0	N	1.20
19 FEB	A-C	1000	SSE	5.0		5	EBB	7.0	15 L	6.0	N	1.50
19 FEB	C-F	1015	SSE	5.0		5	EBB	7.0	15 L	6.0	N	2.05
19 FEB	I-K	1100	SE	10.0		4	EBB	7.0	10 L	6.0	N	1.40
19 FEB	H	1145	SE	10.0		3	EBB	7.0	10 L	6.0	S	.52
21 FEB	A	1400	SW	6.0	.073	3	EBB	3.0	< 5 L	8.0	N	.53

TABLE II (continued)

SUMMARY OF LONGSHORE CURRENTS, WIND, TIDE AND SURF CONDITIONS

DATE	LOC	TIME	WIND		m	TIDE		SURF			LONGSHORE CURRENTS	
			DIR	SPD (KNOTS)		HGT (FT)	STG	H_b (FT)	a_b (DEG)	T (SEC)	DIR	SPD (FT/SEC)
21 FEB	C-D	1410	SW	6.0	.073	3	EBB	3.0	< 5 L	8.0	N	1.63
21 FEB	K	1520	W	4.0	.092	2	EBB	3.0	< 5 R	8.0	S	1.87
21 FEB	J	1520	W	4.0	.092	2	EBB	3.0	< 5 R	8.0	-	0
21 FEB	I	1530	W	4.0	.092	2	EBB	3.0	< 5 R	8.0	S	1.73
5 MAR	F-G	0930	NNE	2.0	.087	6	EBB	4.0	30 L	8.5	N	1.39
5 MAR	A-C	1015	NE	4.0	.087	5	EBB	4.0	30 L	8.5	N	1.64
5 MAR	C-F	1020	NE	4.0	.087	5	EBB	4.0	30 L	8.5	N	2.16
5 MAR	I-K	1100	ENE	4.0	.106	3	EBB	4.0	5 L	8.5	N	1.64
11 MAR	C	0830	SE	4.5	.061	0	SLK-L	4.0	< 5 L	8.2	-	0
11 MAR	C-D	0830	SE	4.5	.061	0	SLK-L	4.0	< 5 L	8.2	N	.57
11 MAR	A	0850	SE	4.5	.061	0	FLD	4.0	< 5 L	8.2	S	.92
11 MAR	E	0945	SE	4.5	.061	1	FLD	4.0	< 5 L	8.2	N	.64
11 MAR	I	1030	ESE	5.5	.113	1	FLD	4.0	< 5 R	8.2	S	2.50
11 MAR	J	1030	ESE	5.5	.113	1	FLD	4.0	< 5 R	8.2	-	0

TABLE II (continued)

SUMMARY OF LONGSHORE CURRENTS, WIND, TIDE AND SURF CONDITIONS

DATE	LOC	TIME	WIND		m	TIDE		SURF			LONGSHORE CURRENTS	
			DIR	SPD (KNOTS)		HGT (FT)	STG	H_b (FT)	a_b (DEG)	T (SEC)	DIR	SPD (FT/SEC)
11 MAR	K	1030	ESE	5.5	.113	1	FLD	4.0	$<$ 5 R	8.2	S	2.50

large angle of approach from the left. There were contributing factors, characteristic of station F, that aided in the generation of an unusually strong longshore current. One factor was that no predominant offshore bar existed at station F and the water deepened rapidly approximately 500 feet offshore. The tide at the time was high and the waves were breaking close to shore, producing a narrow surf zone. It is believed that a narrow surf zone with the same amount of wave energy expended in breaking will generate stronger currents. This effect was noticed at stations I and K when no rip currents existed on 21 February and 11 March. The surf zone was narrower at these stations where the predominant offshore bar did not exist and higher currents resulted than at station J. Station J was shielded by a predominant offshore bar which was exposed at extremely low tide as shown in Figure 5. The surf zone was wider at J and the energy was expended in breaking on the bar. Near this station, the longshore currents that were generated nearshore were negligible on 21 February and 11 March. This particular offshore bar apparently contributed to a counterclockwise gyre circulation between station J and the rip current at station K observed on 19 February and on 5 March. On both days unusually large breaker angles from the left were observed. This large breaker angle on 5 March generated strong northerly currents both south of the canyon head and north of the canyon head.

Longshore currents from station G north to the channel were very weak and intermittent, or non-existent; therefore, data from this area was not used.

In summarizing the rip current data, (Table III), it can be noticed that the rip currents appear adjacent to the offshore bars or between them but not across them. Rip currents appeared at all stages and heights of the tide and under all surf conditions. The rip currents at

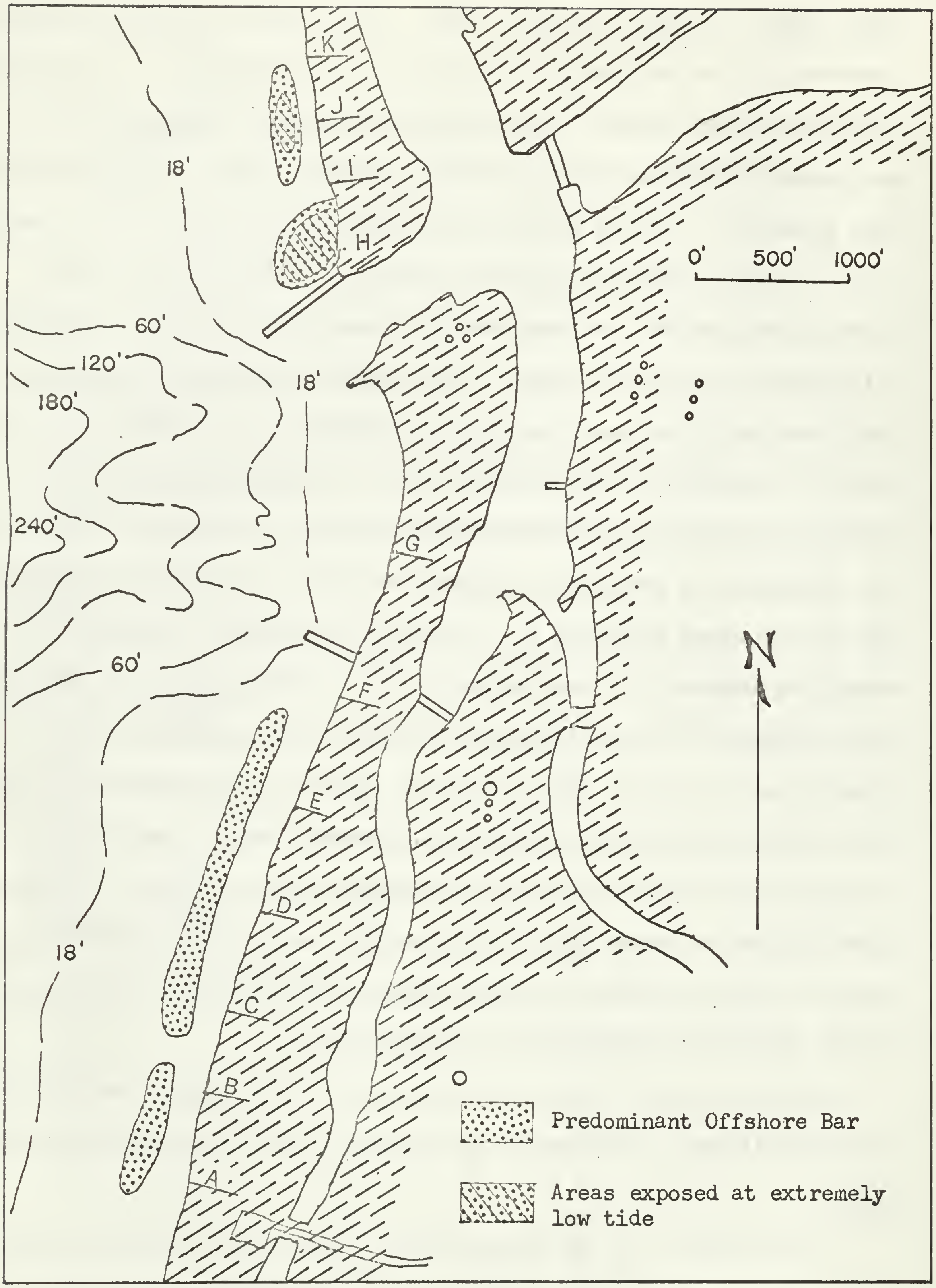

Figure 5.

Offshore Bars

TABLE III

SUMMARY OF RIP CURRENTS

DATE	TIME	LOC	TIDE		SURF			SPD
			HGT (FT)	STG	H_b (FT)	a_b (DEG)	T (SEC)	(FT/SEC)
13 JAN	1400	A	2	FLD	2.5			
21 JAN	1330	A	2	EBB	2.0	<5 R	6.0	
21 JAN	1345	B-C	2	EBB	2.0	<5 R	6.0	
28 JAN	1350	H	3	FLD	5.0	<5 R	8.6	1.35
28 JAN	1545	F	3	EBB	5.0	<5 L	8.6	
10 FEB	1415	I	4	SLK-H	4.0	<5 R	7.0	
11 FEB	1200	B-C	2	FLD	4.0	<5 L	8.3	
11 FEB	1230	F	2	FLD	4.0	<5 L	8.3	
11 FEB	1400	H	3	FLD	4.0	<5 R	8.3	1.61
19 FEB	1100	K	4	EBB	7.0	10 L	6.0	
19 FEB	1145	H	3	EBB	7.0	10 L	6.0	1.42
21 FEB	1450	F	3	EBB	3.0	<5 L	8.0	1.77
21 FEB	1600	H	1	EBB	3.0	<5 L	8.0	.83
5 MAR	1100	K	3	EBB	4.0	5 L	8.5	
11 MAR	0850	A	0	FLD	4.0	<5 L	8.2	
11 MAR	0945	F	1	FLD	4.0	<5 L	8.2	1.84

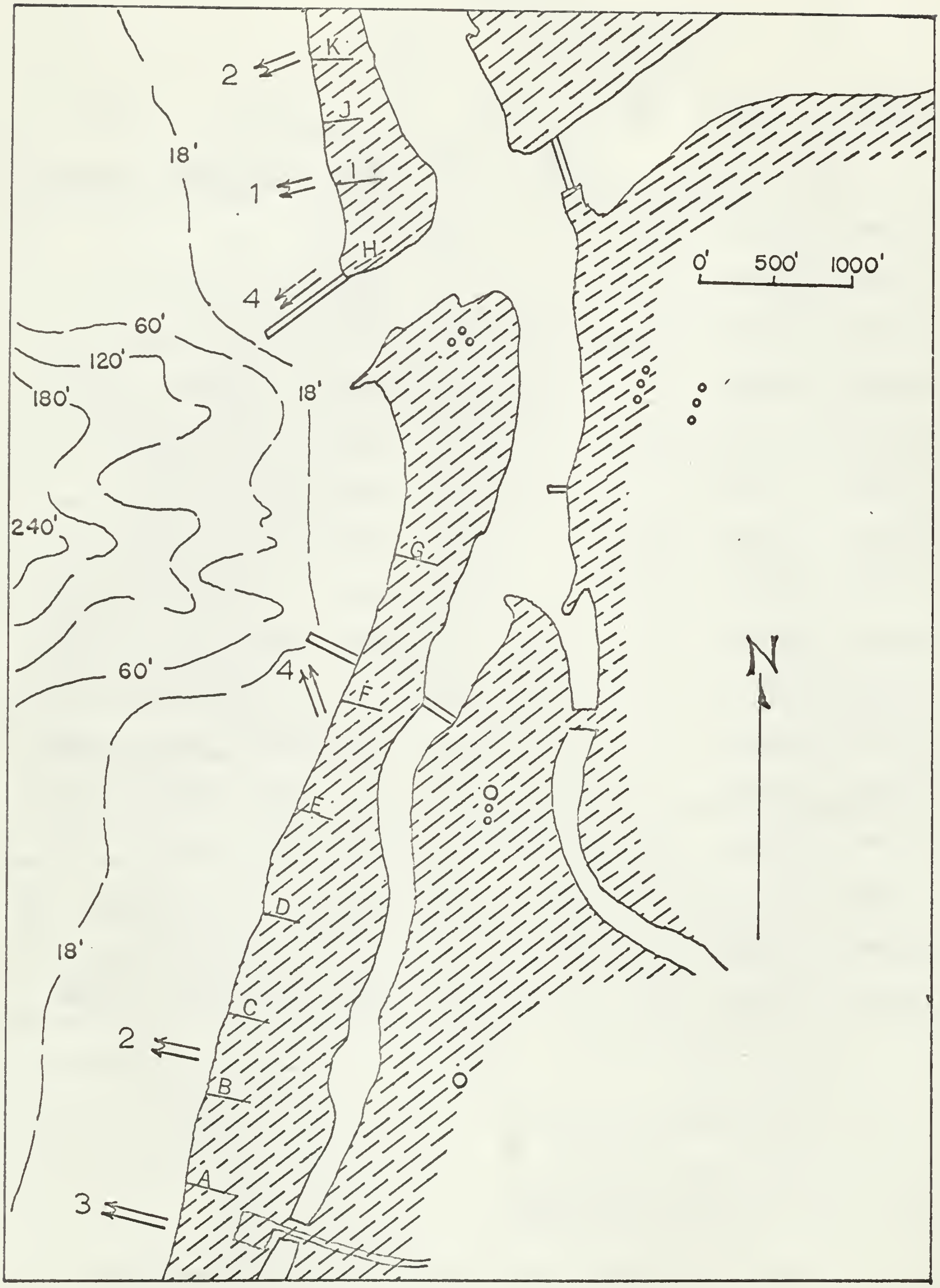

Figure 6.

Frequency of Occurrence of Rip Currents

stations F and H were the most frequently occurring, as shown in Figure 6. They are again shown in the average circulation picture in Figure 7. It was possible to measure the rip current speeds at stations F and H since the rip current at station H was parallel to the jetty and the rip current at F had a longshore component that could be measured. The location of the rip current at station H is in agreement with the findings of Shepard and Inman [10]. Both of these rip currents are considered important in that they deflect suspended sand in the surf zone toward the head of the canyon.

As shown in Table IV, in general, the average flow was toward the head of the canyon from either side. The average speed on the south side of the canyon, between stations A and G in the table, increased toward the rip current at station F and was weak beyond, implying that the major portion of the flow was deflected toward the head of the canyon at this point. On the north side between stations K and H the flow decreased slightly as it approached the jetty and the rip current at station H, where the flow was deflected seaward (Figure 7). The jetty, obstructing the longshore current flow, could possibly be the source of the large bar deposited at station H. As the current is slowed by the jetty it may drop part of its sediment load thus forming a bar.

5. Interpretation of Results

Comparison with Theory

Observed current speeds were compared with speeds calculated using equations (13) and (14). These results are listed in Table V. This comparison was made using the observed velocity as the reference. The error is then equal to the calculated velocity minus the observed velocity, divided by the observed velocity, expressed in %; therefore, a positive error indicates that the calculated velocity was greater than the

TABLE IV

AVERAGE LONGSHORE CURRENT VELOCITIES MEASURED

Location	Direction	Average Speed (feet/sec)
A - B	North	0.56
B - C	North	.59
C - D	North	1.23
D - E	North	1.40
E - F	North	1.33
F - G	North	.70
H - I	South	.46
I - J	South	.55
J - K	South	.57

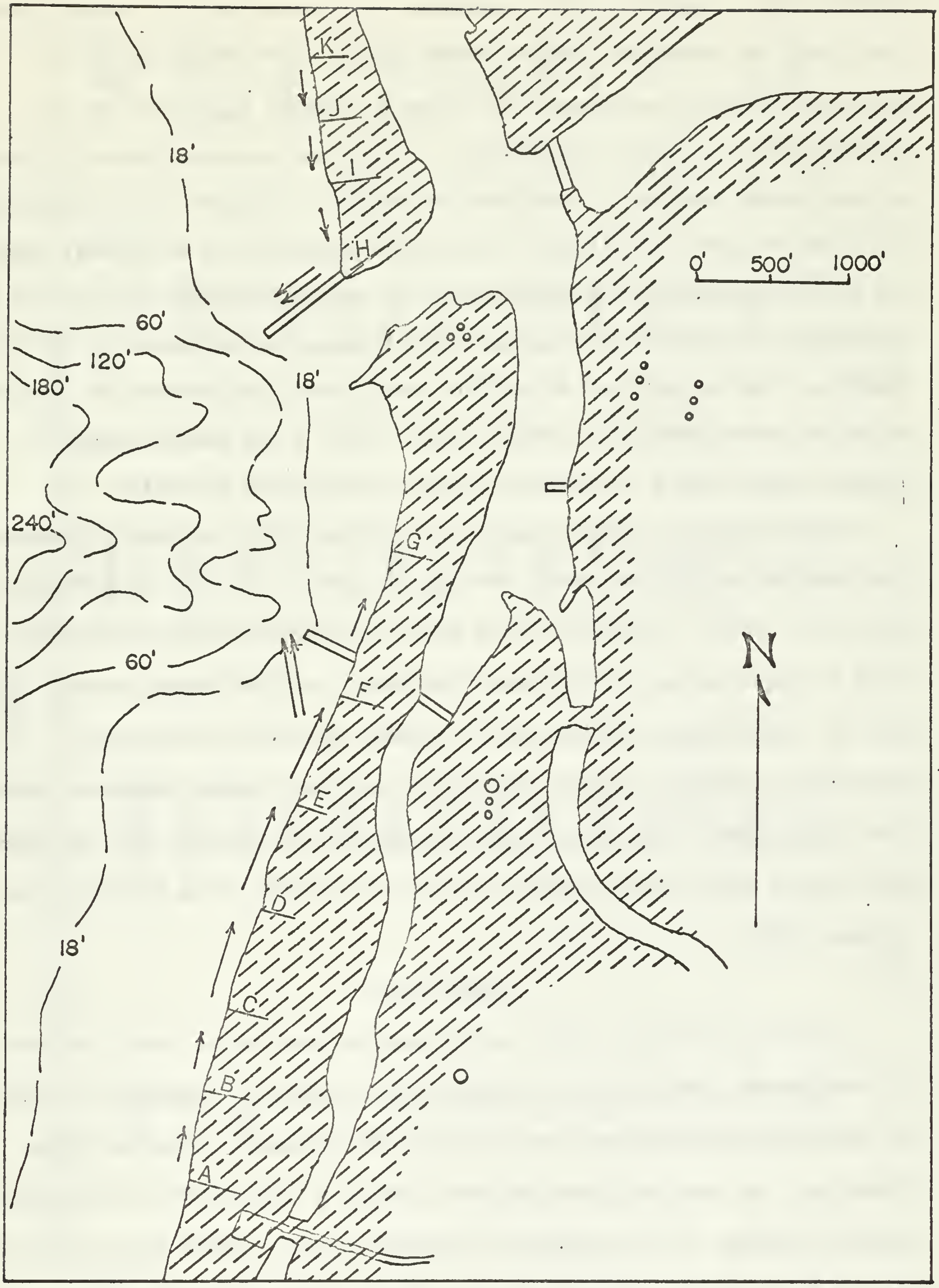

Figure 7.

Average Circulation Pattern

observed and a negative error indicates that the calculated velocity was less than the observed. Since breaker angles were considered to be accurate within five degrees, the value of breaker angle used in the calculations was chosen subjectively, within the accuracy limits, to give an equivalent scatter of calculated velocities both less than and greater than the observed velocities. To show the significance of breaker angle in the calculations, velocities have been calculated using 15, 20, and 30 degrees for observations when the breaker angle was estimated to be 30 degrees. The increase of calculated velocities with increase of breaker angle was even greater for small angles, where a one degree change in breaker angle gave a 50 percent change in calculated velocity.

Considering all breaker angles, the average error between calculated and observed velocities using equation (13) was + 22% and using equation (14) was + 205%. For observations where the breaker angle was greater than 10 degrees, the average error increased to +354% using equation (13), and to + 1061% with equation (14). Without exception, calculated velocities exceeded observed velocities when the breaker angle was greater than 10 degrees. Neglecting angles of approach of greater than 10 degrees, the average error using equation (13) was - 26% and using equation (14) it was + 70%.

Limitations

A period of daily or twice daily observations for at least one year is considered necessary for a complete description of longshore currents to avoid misinterpretation due to daily and seasonal variations [11]. Therefore, the results presented here should be considered to give only a general picture of the longshore circulation and to apply only on the days and at the actual positions of observation. However, the time period covered and the frequency of observations compare favorably with the previous studies by others; thus a comparison of results is not unreasonable.

TABLE V

A COMPARISON OF OBSERVED CURRENTS WITH CURRENTS CALCULATED USING EQUATIONS (13) and (14)

SPD (observed) (ft/sec)	a_b (deg)	SPD (eqn 13) (ft/sec)	% ERROR	SPD (eqn 14) (ft/sec)	% ERROR
0.398	2.5	0.408	+ 2.51	0.821	+ 106.
.423	2.5	.453	+ 7.10	1.08	+ 156.
.700	2.5	.719	+ 2.72	3.30	+ 371.
1.35	2.5	.692	- 48.7	3.46	+ 156.
.620	2.5	.590	- 4.84	1.54	+ 148.
1.01	2.5	.647	- 35.9	2.56	+ 153.
.620	2.5	.590	- 4.84	1.54	+ 148.
.945	2.5	.608	- 35.7	1.78	+ 88.4
1.20	2.5	.556	- 53.6	1.23	+ 2.50
.967	2.5	.527	- 45.5	1.46	+ 51.0
1.46	2.5	.587	- 59.6	1.46	± 0.
.886	2.5	.433	- 51.2	2.15	+ 143.
.802	2.5	.433	- 46.0	.968	+ 27.0

TABLE V (continued)

SPD (observed) (ft/sec)	a_b (deg)	SPD (eqn 13) (ft/sec)	% ERROR	SPD (eqn 14) (ft/sec)	% ERROR
1.82	2.5	0.390	- 78.5	0.692	- 61.9
.420	2.5	.390	- 7.14	.692	+ 64.8
2.79	7.5	2.72	- 2.51	2.44	- 12.5
1.42	7.5	2.79	+ 96.5	2.78	+ 95.7
2.04	7.5	2.79	+ 36.7	3.66	+ 79.4
1.50	7.5	1.75	+ 16.7	3.66	+ 144.
.529	4.5	.741	+ 40.2	2.96	+ 460.
1.12	4.5	.852	- 23.9	2.96	+ 164.
1.87	4.5	1.13	- 39.6	3.93	+ 150.
1.73	4.5	1.13	- 34.7	3.73	+ 115.
1.39	15.0	3.93	+183.	10.7	+ 670.
1.39	20.0	5.23	+276.	13.8	+ 894.
1.39	30.0	7.80	+462.	18.7	+1245.
2.16	15.0	4.02	+ 86.1	12.0	+ 455.
2.16	20.0	5.30	+145.	15.4	+ 614.

TABLE V (continued)

SPD (observed) (ft/sec)	a_b (deg)	SPD (eqn 13) (ft/sec)	% ERROR	SPD (eqn 14) (ft/sec)	% ERROR
2.16	30.0	7.89	+ 265.	20.8	+ 863.
1.64	15.0	4.02	+ 145.	12.0	+ 632.
1.64	20.0	5.30	+ 223.	15.4	+ 839.
1.64	30.0	7.89	+ 381.	20.8	+1168.
.572	2.5	.526	- 8.04	1.41	+ 146.
.916	2.5	.526	- 42.5	1.41	+ 53.8
.636	2.5	.526	- 17.3	1.41	+ 121.
1.11	2.5	.526	- 52.5	1.41	+ 27.1
2.50	2.5	.617	- 75.4	2.61	+ 4.4
2.50	2.5	.617	- 75.4	2.61	+ 4.4

OVERALL AVERAGES

	SPD (observed)	SPD (eqn 13)	% ERROR	SPD (eqn 14)	% ERROR
All a_b	1.25	1.53	+ 22.4	3.81	+ 205.
Only $a_b > 10$	1.73	7.86	+ 354.	20.1	+1061.
Only $a_b < 10$	1.20	0.87	- 26.4	2.12	+ 69.6

Determination of the various parameters involved in producing longshore currents has inherent inaccuracies due to the methods of determination used. Again, the methods used here compare favorably with previous investigations. Two limitations should be realized when interpreting the average errors between calculated and observed velocities presented in Table V. One is the quasi-subjective choice of breaker angle to give an equivalent scatter and the second concerns the value of the hydraulic roughness coefficient used. In the calculations using equation (13), the value used for k was that empirically determined by Inman and Quinn [9] for the beach at Oceanside, California, and was derived from bottom longshore current measurements. The beach at Moss Landing is reasonably similar to that at Oceanside so that the use of this value for k should not introduce a large error. According to Quinn [9], k includes not only frictional effects, but measurement errors and inadequacies of the theory as well, so it was decided not to determine a value of k for Moss Landing. With these limitations in mind, one may consider the results of this study to be comparable to previous work.

6. Summary and Conclusions

This thesis has dealt with a very important and interesting oceanographic phenomenon, longshore currents. It has been shown that the knowledge of and ability to predict longshore currents is of importance to the business and residential community, to those concerned with the construction of structures on the beach, and to the U. S. Navy for the planning and conduct of amphibious operations. A review of previous studies on longshore currents has been presented and a comparison has been made between longshore currents predicted by theory and those observed at Moss Landing. Finally the results of the study of longshore circulation at Moss Landing are presented and discussed.

From consideration of the results of this investigation, certain conclusions can be made concerning longshore circulation at Moss Landing during the winter season. The average direction of the longshore currents was toward the head of Monterey Submarine Canyon from both sides. This was due primarily to the predominant wave approach angle being within the 22 degree envelope as shown in Figure 2. For breaker angles outside this envelope, the current flowed in the same direction on either side of the canyon; the direction depended on whether the waves approached from the south or north. Thus it was concluded that breaker angle was the most important parameter in determining current direction when this angle was greater than five degrees. In addition, fewer rip currents were found when the breaker angles were large, as postulated by Putnam, Munk and Traylor [8].

In testing the results of this investigation with predictions using theoretical formulas, the momentum approach of Putnam, Munk and Traylor [8] was determined to be the most accurate. This theory predicts excessively large longshore current velocities for large breaker angles as do all of the prediction formulas. However, the major discrepancy in the theory was the empirical determination of the hydraulic roughness coefficient; this coefficient must be determined for each area before this theory can be considered specifically applicable.

No relationship was found between surface longshore currents near the head of Monterey Submarine Canyon and bottom currents in the canyon head. Gatje and Pizinger [6] found that the current near the bottom in the head of the canyon, offshore from Moss Landing, was related to the stage of the tide. This current flowed seaward or down the canyon during flood tide and shoreward or up the canyon during ebb tide. The longshore currents measured in the Moss Landing investigation showed no such

relation to the direction of the tidal flow.

Although there was no relationship between the direction of tidal flow and longshore currents, the height of the tide had a very pronounced effect, in that the height of the tide changes the bottom topography relative to the surface of the water. It also changes the slope, especially in cases where the beach face is concave; thus at high water, the slope at the shoreline is relatively steep compared to low water when the slope at the shoreline is relatively flat. The tidal stage also changes the position where the waves break since the point of breaking for a given length wave is determined by the depth of the water. This varying water depth over the offshore bar may well be the factor that caused the difference between currents predicted by theory and those that were observed. An exposed or nearly exposed offshore bar at low water acts as a breakwater and prohibits or greatly restricts generation of a current behind the bar. At higher levels of the tide, offshore bars have less effect on the longshore current.

Longshore current speeds were heavily dependent upon beach slope with steeper slopes giving higher velocities as is predicted by theory and as shown in Table II. In cases of nearly constant beach slope, breaker height was quite significant in determining current speeds, with increasing heights yielding higher speeds. It was not possible to determine the exact contributions of wave height or beach slope since both of these parameters varied from day to day and even during the period of one investigation.

7. Recommendations and Acknowledgements

For future investigations of longshore currents, the following recommendations are offered to enhance the accuracy and therefore the significance of the study: precise measurement of all parameters with particular attention to breaker angle and beach slope, using aerial

photography whenever possible; more frequent observations over a longer time interval, even if a reduction in area covered is necessary; simultaneous observations at closely spaced positions within the area since all of the parameters change with time; and, the use of an amphibious craft to study currents in the seaward extension of the surf zone.

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BIBLIOGRAPHY

1. Bascom, W. Waves and Beaches. Doubleday, 1964.

2. Brebner, A. and J. W. Kamphius. Model tests on the relationship between deep-water wave characteristics and longshore currents. Proceedings of Ninth Conference on Coastal Engineering, 1951: 191-196.

3. Chiu, Tsao-Yi and Per Bruun. Computation of longshore currents by breaking waves. Florida Engineering and Industrial Experiment Station Technical Paper No. 279, Vol. VXIII, No. 3, March 1964.

4. Forrest, D. R. A method of estimating wave direction. The Bulletin of the Beach Erosion Board, April, 1950: 31-37.

5. Galvin, C. J. Jr. and P. S. Eagleson. Experimental study of longshore currents on a plane beach. U. S. Army Coastal Engineering Research Center Technical Memo No. 10, January, 1965.

6. Gatje, P. J. and D. D. Pizinger. "Bottom Current Measurements in the head of Monterey Submarine Canyon". Unpublished Master's thesis, The U. S. Naval Postgraduate School, Monterey, 1965.

7. King, C. A. M. Beaches and Coasts. Edward Arnold Ltd., 1959.

8. Putnam, J. A., W. H. Munk and M. A. Traylor. The prediction of longshore currents. Transactions, American Geophysical Union Vol. 30, No. 3, June, 1949: 337-345.

9. Quinn, W. H. Currents in the surf zone. Proceedings of Second Conference on Coastal Engineering, 1951: 24-36.

10. Shepard, F. P. and D. L. Inman. Nearshore circulation. Proceedings of First Conference on Coastal Engineering, 1950: 50-59.

11. Shepard, F. P. Longshore current observations in Southern California. U. S. Army Corps of Engineers, Beach Erosion Board, Tech. Memo No. 13, 1950.

12. Shepard, F. P. Submarine Geology. Harper and Row, 1963.

13. Shore Protection Planning and Design. U. S. Army Corps of Engineers, Beach Erosion Board, Tech. Rep. No. 4, 1961: 61-86.

14. Tide Tables West Coast of North and South America, 1966. U. S. Department of Commerce, U. S. Coast and Geodetic Survey, U. S. Government Printing Office, 1966.

15. Wiegel, R. L. and D. A. Ellis. Surf characteristics and surfmanship. Manual on Amphibious Oceanography. Amphibious Branch, Office of Naval Research, University of California, 1952: Sect. 7, 8, 9.

16. Wiegel, R. L. Oceanographical Engineering. Prentice-Hall, 1964.

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13. ABSTRACT

Longshore currents were measured in the surf zone in the vicinity of Moss Landing on both sides of the head of Monterey Submarine Canyon. The measurements were made utilizing drift bottles introduced at 50 to 100 feet offshore. For the period covered, January through March 1966, the majority of the longshore currents measured were directed toward the canyon from both sides. It was found that the height of the tide and the offshore bar configuration have a considerable effect on the longshore circulation, in addition to the wave and beach parameters which have been suggested by previous investigators. A review is made of laboratory and field observations of longshore currents to date and a comparison is made between the results of this investigation and previous studies in other geographical areas.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
DRIFT BOTTLES						
LONGSHORE CURRENTS						
MOSS LANDING						
RIP CURRENTS						
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